U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A030 955

Nonmetallic Waterstops

Army Engineer Waterways Experiment Station Vicksburg Miss

Oct 70

MISCELLANEOUS PAPER C-70-22

NONMETALLIC WATERSTOPS

by

G. C. Hoff, B. J. Houston

October 1970

Published by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

MISCELLANEOUS PAPER C-70-22

NONMETALLIC WATERSTOPS

by

G. C. Hoff, B. J. Houston

October 1970

Published by: U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS

FOREWORD

This paper was prepared at the request of ACI Committee 504 on "Joint Sealants" for consideration for inclusion in a Symposium on Joint Sealants to be held at the ACI 1971 Annual Meeting on 6-12 March 1971 in Denver, Colorado.

The various investigations which provided the majority of the information and data discussed herein were conducted by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., under the sponsorship of the Office, Chief of Engineers, under Engineering Studies Item 012, "Investigation of Waterstops for Construction Joints." The work was accomplished during the period since 1956 under the general supervision of Mr. T. B. Kennedy, former Chief, and Mr. Bryant Mather, present Chief of the WES Concrete Division, Mr. J. M. Polatty, Chief of the Engineering Mechanics Branch, and Mr. R. V. Tye, Jr., Chief of the Engineering Sciences Branch. Mr. B. J. Houston was the project leader for the majority of the work discussed, and Mr. G. C. Hoff and he prepared this paper.

SYNOPSIS

Nonmetallic waterstops having suitable properties for use in joints in hydraulic structures of concrete have been made successfully from natural rubber, synthetic rubber, and polyvinyl chloride. To perform satisfactorily, a waterstop must have sufficient strength and extensibility to avoid being ruptured by joint movement, and it must maintain strength and extensibility over the temperature range and in spite of chemical attack from the environment of service. It must also have suitable dimensions and configuration and be installed so as to avoid waterflow around the embedded ends.

Field and laboratory studies have led to the conclusion that suitable waterstop materials should have a tensile strength of at least 1400 psi (plastic), 2000 psi (rubber), the ability to elongate 280 percent (plastic) or 360 percent (rubber), and to have various levels of maintenance of relevant properties after various chemical and thermal exposures.

NONMETALLIC WATERSTOPS

by

G. C. Hoff and B. J. Houston

The principal function of a waterstop is to serve as a barrier to the passage of water through, across, or along a construction joint in a concrete structure exposed to water on one or more surfaces. Such structures include dams, locks, power plants, pumping plants and canal linings.

MATERIALS

Steel, lead, wrought iron, and copper have been used as waterstop materials generally as rigid plates or flexible diaphragms. Copper has been most used because of its ductility. It has a tensile yield strength of 30-40,000 psi with a modulus of elasticity of $15\text{-}16 \times 10^6$ psi. Copper is nevertheless too stiff to accommodate large relative movements of a concrete joint. It is also easily damaged during concrete vibration. Repeated opening and closing of the joint may cause fatigue failure.

To overcome the shortcomings of metal waterstops, rubber waterstops were introduced in the early 1930's and used in the construction of the Imperial Dam on the Colorado River and the All-American Canal in Southern California in 1935.[1] A variety of different rubber waterstop configurations were proposed. Those used by the Bureau of Reclamation between

1935 and 1953 were described by Allen and Higginson.[1] Rubber waterstops were also discussed by Kellam and Loughborough[2] in their account of the use of waterstops by the Hydro-Electric Power Commission of Ontario. A typical rubber waterstop can have a tensile strength of 3000 psi, a 500 percent elongation, and a modulus of elasticity at break of 600 psi.

Plastic waterstops were introduced in the midfifties with such plastics as polyvinyl chloride, polyethylene, polyurethane, styrene-butadiene, and others being used. Polyvinyl chloride, however, is the material usually used for plastic waterstop. The mechanical properties of any of the various plastics used can be varied widely by changing the formulation or method of compounding or both. The plastic used in a typical plastic waterstop, however, might be expected to have a tensile strength of 2000 psi, an elongation of 300-400 percent, and a modulus of approximately 600 psi.

CONFIGURATIONS AND APPLICATIONS

The four basic shapes for nonmetallic waterstops are shown in fig. 1. They are commonly called the: (a) labyrinth, (b) flat corrugated, (c) two-bulb dumbbell, and (d) three-bulb dumbbell. Many variations of these shapes exist, including those having noncircular bulbs or additional vertical fins on the horizontal flange or center bulbs of shapes (b) or (d) or both.

Waterstops of shapes (b), (c), and (d) are used by embedding one-half of their width in the concrete on each side of the joint so that the material spans the joint. The side bulbs of waterstops (c) and

(d) are greater in diameter than the web thickness and thus resist the tendency of the waterstop to be pulled out when joint movement occurs. The ribs or corrugations on type (b) perform the same anchorage function. Hollow-center bulbs (O-bulbs) as shown for (b) and (d) provide additional flexibility to the waterstop and help reduce the shearing stresses that occur in the waterstop when it is deformed transversely.

The use of waterstops (b), (c), and (d) requires splitting and bracing of the concrete form so that the waterstop can protrude from one placement into the area where the adjacent placement will occur. Labyrinth waterstops (type (a)) are designed to lie within the joint rather than extend through it and do not require splitting of the form. They are usually used where the joint is classified as a nonworking joint, i.e., little or no differential joint movement is anticipated. The need to split the form may also be avoided with waterstop of types (b), (c), and (d) if the flange to be embedded in the second placement of concrete is split and the halves are turned 90 deg and installed within the form for the first placement. These halves must be brought together and embedded in the second concrete placement. Waterstops of these designs are referred to as nail-on, unfold waterstops as opposed to the nail-on, labyrinth type.[3]

Dumbbell and flat corrugated type waterstops are usually used across working joints, i.e., joints where movements are expected.

Two-bulb dumbbells are generally used across joints where a predetermined amount of total lateral movement is expected or where continued lateral movement occurs through continued expansion or contraction of the joint. In both instances, the movement stretches the waterstop laterally across its width (fig. 2a). The three-bulb waterstop is usually used for unkeyed vertical or horizontal joints. In this instance, the joint movement can occur transversly (fig. 2b) across the thickness of the waterstop as well as laterally. When just transverse movement occurs, the center bulb is deformed as shown in fig. 3a. When both transverse and lateral movements occur simultaneously, the deformations as shown in fig. 3b result. The flat corrugated waterstop is used in the same situations described for the dumbbell types.

PERFORMANCE

To avoid costly and difficult if not impossible replacements of malfunctioning waterstops in a concrete structure, the waterstop should have a useful life comparable to that of the structure. Such factors as long-term durability, temperature sensitivity, extensibility, and water retentivity are all essential in establishing what the useful life of a waterstop might be.

Durability

Performance requirements for waterstops in concrete structures vary greatly, depending on location and type of structure. The ideal situation would be to have one material for universal use. It is more

likely, however, that under some conditions one material will perform better while under other conditions another will perform better. In order to establish the long-term durability of nonmetallic waterstops, the U. S. Army Corps of Engineers initiated a research program in 1956 to determine the effects of different exposure conditions on various types of nonmetallic waterstops.[4,5,6] Specimens of natural rubber, synthetic rubber, and polyvinyl chloride were studied in both stressed and unstressed conditions for the following exposure conditions: (a) exposure to freezing and thawing in a marine environment, (b) exposure to wetting and drying in a warm marine environment, (c) outdoor exposure in a moderate climate, (d) indoor exposure (air without sunlight), (e) exposure in a weak solution of sodium and magnesium sulfate, (f) exposure to cold contaminated water, (g) exposure to cold fresh water, (h) exposure to warm contaminated water, and (i) exposure to warm fresh water. Visual inspections of the exposed specimens were made periodically for a time span of seven to nine years. Exposures (a) and (b) were obtained by placing the waterstop specimens at mean tide elevation on the beaches of Treat Island, Maine, and St. Augustine, Florida, respectively. Exposures (c), (d), and (e) were obtained at the U. S. Army Engineer Waterways Experiment Station concrete laboratory at Jackson, Mississippi. Exposures (f) and (g) were obtained where the Granite City, Illinois, sewage ditch empties into the Chain-of-Rocks Canal on the Mississippi River and at the upper river guidewall extension cells of the Mississippi River Lock No. 26 at Alton, Illinois, respectively.

Exposures (h) and (i) were obtained in an oil refinery waste drainage ditch near New Orleans, Louisiana, and in the Bayou Sorrel Lock on the Plaquemine-Morgan City Alternate Route Intercoastal Waterway in Louisiana, respectively.

The unstressed condition of the waterstop samples was achieved by hanging the waterstops from a seasoned oak strip or metal pipe. The stressed condition was achieved by bending the waterstop around the strip or pipe.

Some exposure tests of embedded waterstops were also conducted at Treat Island, St. Augustine, and Jackson outdoors. These samples consisted of 6-in. lengths cut from the finished waterstops. The ends of these lengths were embedded in 6- by 6-in. concrete cubes which were allowed to harden for 14 days. At that time, the joint was opened 1 in. and blocked in this position with the waterstop material stretched.

The detailed results of this exposure study have been reported by Houston.[4,5,6]

Results of the visual inspections of the specimens are summarized in table 1. All butyl, neoprene, natural, and service rubber test samples were affected by exposure at most of the exposure stations, with the more pronounced effects being on the specimens exposed at Jackson outdoors, at St. Augustine, and at Granite City in contaminated water.

A number of physical tests were performed on the weathered waterstops to evaluate changes in their physical properties. The test methods

employed in nonmetallic waterstop evaluations are listed in table 2. With the exception of butyl rubber, all other types of rubber experienced decreases in tensile strength and elongation with respect to the as-received, no-stress condition. All types of rubber experienced increases in the stress level at 300 percent elongation and in the hardness. The compressive set of butyl, service, and one type of neoprene decreased and increased for the natural rubber and one type of neoprene. Generally, of the natural and synthetic rubber materials from which the waterstops were made, neoprene best withstood most exposure conditions with natural, butyl, and service rubber following in that order. All rubbers were more affected by exposure when stressed than when unstressed, and less affected when embedded in concrete than when not embedded. Those specimens exposed to sunlight and air experienced more degradation with respect to performance than those that were immersed or indoors.

The polyvinyl chloride (PVC) specimens represented material produced by five manufacturers, with one of the manufacturers providing four different PVC formulations. All weathered PVC specimens showed increases in tensile strength with respect to the as-received, no-stress material. The general tendency was for increased ultimate elongations with some exceptions. All weathered PVC specimens lost their ability to maintain their structural integrity to temperatures as low as those obtained by the unweathered specimens. All four formulations from the one manufacturer showed increased low temperature stiffness with exposure but the other products all experienced decreases. As with rubber, PVC was more

affected by hot sunlight and air than by other exposure conditions to which it was subjected. It was more affected when stressed than when unstressed, and less affected when embedded in concrete than when not. A number of the PVC specimens appeared to lose their plasticizer with exposure and became hard and brittle.

Temperature sensitivity

The performance of a waterstop in a given environment is influenced by temperature regardless of its weathered condition. Tests of waterstops made of natural rubber, neoprene, and PVC[7] were conducted in an environmental cabinet (fig. 4) to determine the effect of reduced temperatures on the ultimate strength and elongation. Reductions from 73 F to 0 F for PVC waterstops produced tensile strength increases from 40 to 100 percent and ultimate elongation reductions from 25 to 70 percent. A similar behavior was observed for the rubbers, but it was not as pronounced. Stressing the PVC and rubbers to 90 percent of their ultimate elongation at 73 F and then reducing the temperatures to -15 F did not induce failure in the specimens. Additional stretching at the -15 F temperature would result in failure, however.

Extensibility

Extensibility of waterstops is an essential characteristic for satisfactory performance. Large joint movements can occur such as the 12- to 14-in. movements experienced in an outlet conduit at West Branch Dam on the Mahoning River in Pennsylvania. This movement resulted in

the rupture of a three-bulb, 9-in.-wide PVC waterstop. As mentioned earlier, the extensibility the waterstop is capable of is temperature dependent and tends to decrease with decreasing temperatures. Full size pieces of waterstop show less ability to elongate than the smaller pieces used for acceptance tests.[7]

Tests of PVC waterstops[8] having eight different shapes representing waterstops used in concrete-lined canals, indicated that, in general, satisfactory performance, indicated by an absence of leakage, could be obtained for lateral joint movements up to 3/8 in These types of waterstops are usually about 2 in. long, yet they could be extended over an additional 2 in. before rupture.

The ability of the waterstop to deform when differential settlement induces transverse movements between blocks containing the waterstop is also essential for a satisfactory performance. The benefits derived from a central O-bulb in the waterstop for this purpose can be seen in fig. 3a. A shear test was conducted[9] on a three-bulb, 9-in.-wide, 36-in.-long waterstop which spanned the joint between concrete blocks. The sides of the waterstop were completely embedded in concrete. The joint had a 1-in. opening. Differential movements of almost 3 in. with no lateral movements of the blocks did not damage the waterstops. Similar tests of a three-bulb, 9-in. waterstop for only lateral movements indicated that movements of 5 in. could be accommodated.[1]

Water retentivity

The ability of waterstops to resist the passage of water has been evaluated[2,11,12] using the test apparatus shown in Fig. 5. The waterstops form a continuous loop and include a splice where the two ends meet. By jacking the top and bottom blocks apart, the waterstop is subjected to elongation. The effectiveness of the waterstop in resisting the flow of water along the joint can then be determined for any desired degree of joint movement.

From this test, it was found that both the corrugated or ribbed-flange waterstops and dumbbell waterstops were effective in retaining water provided care is exercised in splicing and embedding them.[2,10] The corrugated or ribbed-flange waterstops appeared to be somewhat more effective, however. It was indicated[2] that when the dumbbell shape was extended the flat web portion of the waterstop was reduced in thickness, leaving only the bulbs at the ends in contact with the concrete. This permitted some seepage. When the corrugated waterstop was extended, the pull was taken by the ribs nearest the center of the waterstop, thus leaving the other ribs and the major part of the waterstop still in contact with the concrete. The rib-flanged waterstops require more care than the dumbbell types during vibration and consolidation of the concrete directly in contact with the waterstop so that the waterstop is not displaced and to ensure that the concrete is worked in between the ribs for maximum surface contact.

Results of a study of labyrinth waterstops[11] indicated that they were as effective in retaining water as other shapes tested provided there is little or no joint movement. Labyrinth waterstops will not tolerate a joint movement of 1/4 in. without their water retentivity being seriously reduced. At joint openings of 1/8 in., these waterstops performed satisfactorily when water pressures were less than 100 psi. The failure of the labyrinth waterstops to retain water when large joint movements occurred was due, in general, to fracture and failure of the concrete contained between the anchor legs of the labyrinth rather than by a rupture of the waterstop itself. The dotted lines in fig. 6 indicate possible areas of the concrete fracture.

To ensure satisfactory water retentivity, the waterstop must be sound, strong, and homogeneous over its entire length, including all splices of the material. Most manufacturers of waterstops will perform splicing in the production plant or furnish field splicing kits along with recommendations as to how to do it. It has been found that in the case of ribbed designs, the continuity of the ribs must be preserved in the area of the splice or leakage will occur.[2] Special tools are available for this purpose. Splices are usually fused, vulcanized, or glued. The tensile strength of a fused splice, used commonly in splicing PVC waterstops, is usually less than the strength of the unspliced material. It will, however, average nearer the strength of the unspliced material than will that of a vulcanized splice of either natural or synthetic rubber.[10] Vulcanized splices are also reduced in

strength with respect to the unspliced material. Glued sleeve splices are generally stronger than vulcanized splices of the same waterstop. Glued lapped splices are not as strong, however, as the vulcanized splices, but can be made stronger by overlapping a greater length.

WATERSTOP SPECIFICATIONS

Based on the knowledge gained from experience in using waterstops and results of investigations,[4-7, 10-12] the Corps of Engineers has developed specifications for the acceptance of rubber and PVC waterstops.[13] A summary of the requirements is shown in table 3. The specimens used in the testing of PVC waterstops are obtained by hot-pressing the finished waterstop into a sheet form and then using appropriate cutting dies, with buffing as necessary. This procedure replaces earlier practices of obtaining specimens of sheet material from the manufacturers with a certification that they represented the same material as used in extruding the waterstop. The hot-press can be seen in fig. 7. Rubber waterstop test samples are obtained by slicing and buffing from portions of the finished waterstop.

Additional information on waterstop specifications can be obtained from references 14 through 16.

REFERENCES

1. Allen, E. A., and Higginson, E., "Waterstops in Articulated Concrete Construction," Proceedings, ACI Journal, vol 52, pp 83-91, Sep 55.

2. Kellam, B., and Loughborough, M. T., "Waterstops for Joints in Concrete," Proceedings, ACI Journal, vol 55, pp 1269-1286, June 1959.

3. ACI Committee 504, "Guide to Joint Sealants for Concrete Structures," Proceedings, ACI Journal, vol 67, pp 489-536, July 1970

4. Houston, B. J., Investigation of Nonmetallic Waterstops; Preliminary Laboratory and Field Exposure Tests, Technical Report No. 6-546, Report 1, May 1960, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

5. Houston, B. J., Investigation of Nonmetallic Waterstops; Progress Report of Laboratory and Field Exposure Tests, Technical Report No. 6-546, Report 3, June 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

6. Houston, B. J., Investigation of Nonmetallic Waterstops; Effect of Exposure, Technical Report No. 6-546, Report 6, January 1968, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

7. Houston, B. J., Investigation of Nonmetallic Waterstops; Effect of Sample Size and Low Temperature on Waterstop Test Results, Technical Report No. 6-546, Report 7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. (DRAFT).

8. Johns, H., Extension Tests on PVC Contraction Joint Forming Waterstops, Report No. ChE-103, September 1959, U. S. Bureau of Reclamation, Denver, Colo.

9. Fabry, J. W., "Shear Test of 9-in. Type A Rubber Waterstop in a 1-in. Expansion Joint, Dos Amigos (Mile 18) Pumping Plant, San Luis Unit--Central Valley Project, Report C-1197, August 1966, U. S. Bureau of Reclamation, Denver, Colo.

10. Houston, B. J., Investigation of Nonmetallic Waterstops; Water Retentivity and Tensile Strength of Splices, Technical Report No. 6-545, Report 4, December 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

11. Houston, B. J., Investigation of Nonmetallic Waterstops; Water Retentivity of Labyrinth-Shaped Waterstops, Technical Report No. 6-546, Report 5, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. (DRAFT).

12. Pepper, L., Investigation of Nonmetallic Waterstops; Evaluation of the Effect-of-Alkalies and Accelerated Extraction Tests, Technical Report No. 6-546, Report 2, March 1961, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

13. U. S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, with quarterly supplements, August 1949, Vicksburg, Miss.

14. Office, Chief of Engineers, DA, Guide Specifications, Civil Works Construction, Standard Guide Specifications for Concrete, CE 1401.01, Washington, D. C.

15. Office, Chief of Engineers, DA, Guide Specifications, Civil Works Construction, Metals, Miscellaneous Materials, and Standard Articles, CE 1402, Washington, D. C.

16. Office, Chief of Engineers, DA, <u>Engineering and Design, Waterstops</u>, EM 1110-2-2102, Washington, D. C.

Table [illegible]

Summary of Condition of Specimens After Exposure* as Determined [illegible]

Specimen No.	Stress Condition	Treat Island	St Augustine	Jackson Outdoors	Jackson Indoors	Jackson Sulfate	St. Louis District Cold Fresh Water**	St. Louis District Cold Contaminated Water	New Orleans District Warm Fresh Water	New Orleans District Warm Contaminated Water
Buty-1	Unstressed	Sound	Sound at 1 yr then lost	Sound	Sound	Sound	Sound at 5 yr	Crazing at 4 yr	Sound at 1 yr then lost	Sound
	Bent	Crazing at 5 yr	Sound at 3 yr then lost	Crazing at 1 yr, cracked at 2 yr	Sound	Sound	Sound at 5 yr	Crazing at 2 yr	Sound at 4 yr then lost	Sound
	Embedded	Sound	Crazing at 3 yr	Sound	--	--	--	--	--	--
NTUR-1	Unstressed	Sound	Sound	Sound	Sound	Sound	Sound at 5 yr	Crazing at 3 yr	Sound	Sound
	Bent	Sound	Sound at 3 yr then lost	Cracked at 1 yr	Sound	Sound	Sound at 5 yr	Crazing at 3 yr	Sound	Sound
	Embedded	Sound	Crazing at [illegible] yr	Sound	--	--	--	--	--	--
NTOR-2	Unstressed	Sound	Sound	Sound	Sound	Sound	Sound at 5 yr	Crazing at 3 yr	Sound at 1 yr then lost	Sound
	Bent	Sound	Cracked at 4 yr	Sound	Sound	Sound	Sound at 5 yr	Crazing at 2 yr	Sound at 4 yr then lost	Sound
	Embedded	Sound	Crazing at 4 yr	Crazing after 5 yr	--	--	--	--	--	--
NN-1	Unstressed	Sound	Crazing at 4 yr	Crazing at 3 yr	Sound	Sound	Crazing at 1 yr	Crazing at 2 yr	Soft at 1 yr, crazing at 5 yr	Sound
	Bent	Crazing at 1 yr	Sound at 3 yr then lost	Crazing at 1 yr, cracked at 2 yr	Sound	Sound	Crazing at 1 yr, cracked at 5 yr	Crazing at 2 yr	Soft at 1 yr, crazing at 5 yr	Sound
	Embedded	Crazing at 3 yr	Crazing at 4 yr	Crazing at 3 yr	--	--	--	--	--	--
NP-2	Unstressed	Sound	Crazing at 4 yr	Sound	Sound	Sound	Crazing at 1 yr	Crazing at 4 yr	Sound at 1 yr then lost	Sound
	Bent	Crazing at 2 yr	Sound at 3 yr then lost	Crazing at 2 yr	Sound	Sound	Crazing at 1 yr, cracked at 5 yr	Crazing at 2 yr	Sound at 4 yr then lost	Sound
	Embedded	Crazing at 4 yr	Crazing at 3 yr	Crazing at 3 yr	--	--	--	--	--	--
SR-1	Unstressed	Sound	Crazing at 4 yr	Crazing at 5 yr	Sound	Sound	Crazing at 1 yr	Crazing at 3 yr	Sound	Sound
	Bent	Cracked at 2 yr, badly cracked at 5 yr	Sound at 3 yr then lost	Badly cracked at 2 yr	Sound	Sound	Crazing at 1 yr, cracked after 4 yr	Crazing at 2 yr	Sound	Sound
	Embedded	Crazing at 3 yr	Crazing at 4 yr	Badly cracked at 2 yr, torn at 8 yr	--	--	--	--	--	--
SR-2	Unstressed	Sound	Cracked at 4 yr	Sound	Sound	Sound	Crazing at 1 yr	Crazing at 3 yr	Sound at 7 yr then lost	Sound
	Bent	Cracked at 1 yr, badly cracked at 5 yr	Cracked at 3 yr	Cracked at 2 yr	Sound	Sound	Crazing at 1 yr, cracked at 4 yr	Crazing at 3 yr, cracked at 4 yr	Sound at 6 yr then lost	Sound
	Embedded	Crazing at 3 yr	Crazing at 3 yr	Completely torn at 1 yr	--	--	--	--	--	--
SR-3	Unstressed	Sound	Cracked at 4 yr	Crazing at 3 yr	Sound	Sound	Crazing at 1 yr	Crazing at 3 yr	Sound	Sound
	Bent	Cracked at 2 yr, badly cracked at 5 yr	Cracked at 3 yr	Badly cracked at 2 yr	Sound	Sound	Crazing at 1 yr, cracked at 4 yr	Crazing at 2 yr, cracked at 5 yr	Sound at 1 yr then lost	Sound
	Embedded	Crazing at 3 yr	Sound	Badly cracked at 2 yr	--	--	--	--	--	--
PVC-2	Unstressed	Sound	Sound at 6 yr then lost	Crazing at 3 yr	Sound	--	--	--	--	--
	Bent	Sound	Sound at 2 yr then lost	Crazing at 2 yr	Sound	--	--	--	--	--
	Embedded	Sound	Crazing at 3 yr	Crazing at 6 yr	--	--	--	--	--	--
PVC-2(2)	Unstressed	-	--	--	--	Sound	Broken when bent at low temperature for inspection at 3 yr	Sound	Sound at 4 yr then lost	Sound
	Bent	-	-	--	--	Sound	Sound	Sound	Sound at 4 yr then lost	Sound
	Embedded	--	-	--	--	--	--	--	--	--

(Continued)

* Specimen conditions given without time limit are conditions after full exposure time.

** All specimens lost after 5-yr exposure as a result of [illegible].

Table 1 (Concluded)

Specimen No.	Stress Condition	Treat Island	St. Augustine	Jackson: Outdoors	Jackson: In-doors	Jackson: Bil-site	St. Louis District: Cold Fresh Water	St. Louis District: Cold Contaminated Water	New Orleans District: Warm Fresh Water	New Orleans District: Warm Contaminated Water
PVC-2A	Unstressed	Sound	--	Sound	Sound	--	--	--	--	--
	Bent	Sound	--	Sound	Sound	--	--	--	--	--
	Embedded	Torn at 2 yr	--	Sound	--	--	--	--	--	--
PVC-2A(2)	Unstressed	--	--	--	--	Sound	Broken when bent at low temperature for inspection at 3 yr	Broken when bent at low temperature for inspection at 2 yr	Sound at 4 yr then lost	Sound
	Bent	--	--	--	--	Sound	Sound	Sound	Sound at 4 yr then lost	Sound
	Embedded	--	--	--	--	--	--	--	--	--
PVC-3	Unstressed	Sound	Sound at 2 yr then lost	Crazing at 5 yr	Sound	--	--	--	--	--
	Bent	Sound	Sound at 2 yr then lost	Crazing at 8 yr	Sound	--	--	--	--	--
	Embedded	Concrete broken at 2 yr	Crazing at 5 yr	Sound	--	--	--	--	--	--
PVC-3(2)	Unstressed	--	--	--	--	Sound	Sound	Sound	Sound at 4 yr then lost	Sound
	Bent	--	--	--	--	Sound	Sound	Sound	Sound at 4 yr then lost	Sound
	Embedded	--	--	--	--	--	--	--	--	--
PVC-3A	Unstressed	Sound	--	Sound	Sound	--	--	--	--	--
	Bent	Sound	--	Sound	Sound	--	--	--	--	--
	Embedded	Sound	--	Sound	--	--	--	--	--	--
PVC-3A(2)	Unstressed	--	--	--	--	Sound	Sound	Sound, one cracked when bent at low temperature	Sound at 4 yr then lost	Sound
	Bent	--	--	--	--	Sound	Sound	Sound	Sound at 4 yr then lost	Sound
	Embedded	--	--	--	--	--	--	--	--	--
PVC-4	Unstressed	Sound	Sound	Crazing at 3 yr	Sound	Sound	Sound Sound	Sound	Sound	Sound
	Bent	Sound	Sound at 2 yr then lost	Crazing at 8 yr	Sound	Sound	Sound Sound	Sound	Sound	Sound
	Embedded	Sound	Crazing at 5 yr	Sound	--	-	-- --	--	--	--
PVC-5	Unstressed	Sound	Sound	Crazing at 3 yr	Sound	Sound	Sound	Sound	Sound at 1 yr then lost	Sound
	Bent	Sound	Sound at 2 yr then lost	Crazing at 8 yr	Sound	Sound	Sound	Sound	Sound at 4 yr then lost	Sound
	Embedded	Sound	Crazing at 5 yr	Sound	--	--	--	--	--	--
PVC-7(2)	Unstressed	--	--	--	--	Sound	Sound	Cracked at 5 yr	Sound	Sound
	Bent	--	--	--	--	Sound	Sound	Crazing at 4 yr	Sound at 4 yr then lost	Sound
	Embedded	--	--	--	--	--	--	--	--	--
PVC-9A(4)	Unstressed	Sound	Sound at 2 yr then lost	--	--	Sound	Sound	Sound	Sound	Sound
	Bent	Sound	Sound at 2 yr then lost	--	--	Sound	Sound	Sound	Sound at 4 yr then lost	Sound
	Embedded	Sound, sample lost 1965	Crazing at 5 yr	--	--	--	--	--	--	--

Table 2

Summary of Tests Normally Performed on Waterstops

Physical Property Evaluated	Test Method Designation: CRD-C[a]	Test Method Designation: FTMS[b] 601	Test Method Designation: ASTM[c]	Type of Waterstop Tested: Rubber	Type of Waterstop Tested: PVC or Other Plastic
Tensile strength	568	4111		X	X
Hardness	569	3021		X	
Low-temperature brittleness	570	5311.1			X
Stiffness	571		D747		X
Accelerated extraction	572				X
Elongation	573	4121		X	X
300 percent modulus	574	4131		X	
Water absorption	575	6631		X	
Compressive set	576	3311		X	
Oxygen aging	577	7111		X	
Effect of alkalies	572			X	

[a] See reference 13.

[b] Federal Test Method Standard 601.

[c] American Society for Testing and Materials Standard Method of Test.

Table 3

Nonmetallic Waterstop Specifications

Method of Test Designation					
CRD-C[13]	ASTM	FTMS 601	Title	No. of Specimens Tested	Requirement
			Specifications for Rubber Waterstops (CRD-C 513[13])		
568	--	4111	Tensile strength	At least 5	Tensile strength, using Die III, not less than...2000 psi
569	--	3021	Hardness, durometer		Hardness, Shore durometer, type A, between 60 and 70
573	--	4121	Elongation, ultimate		Ultimate elongation using Die III, not less than...350%
574	--	4131	Tensile stress		300% modulus, not less than... 900 psi
575	--	6631	Change in weight, water immersion		Water absorption after 7 days immersion at 73.4 $\pm$ 2 F calculated as percent by weight, not more than. .5
576	--	3311	Compression set		Compression set, not more than...30%
577	--	7111	Oxygen pressure test		Tensile strength after aging, oxygen bomb method, not less than...80%
Job-made and factory-made splices					
568	--	4111	Tensile strength as directed		Tensile strength, using Die III, expressed as a percentage of the strength of the unspliced material...not less than 50

(Continued)

Table 3 (Concluded)

Method of Test Designation					
CRD-C[13]	ASTM	FTMS 601	Title	No. of Specimens Tested	Requirement
Specifications for Polyvinyl Chloride Waterstops (CRD-C 572[13])					
568	--	4111	Tensile strength	5	Tensile strength, using Die III, not less than...1400 psi
573	--	4121	Ultimate elongation	5	Ultimate elongation, using Die III, not less than...280%
570	D746	--	Method of test for brittleness temperature of plastics and elastomers by impact	3	Low-temperature brittleness, no sign of failure such as cracking or chipping at...-35 F
571	D747	--	Method of test for stiffness in flexure of plastics	3	Stiffness in flexure, 1/2-in. span, not less than...400 psi
572	--	--	CE specifications for polyvinyl chloride waterstops - accelerated extraction	5	Ultimate elongation, using Die III, not less than...300% Tensile strength, using Die III, not less than...1500 psi
572	--	--	CE specifications for polyvinyl chloride waterstops - effect of alkalies	3	Change in weight after 7 days, between...-0.10 and +0.25% Change in Shore durometer reading after 7 days, not more than ± 5
Job-made and factory-made splices					
568	--	4111	Tensile strength	As directed	Tensile strength, using Die III, not less than 1120 psi

20

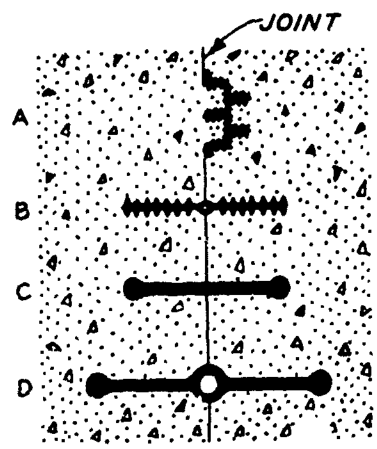

Fig. 1. Typical nonmetallic
waterstop shapes

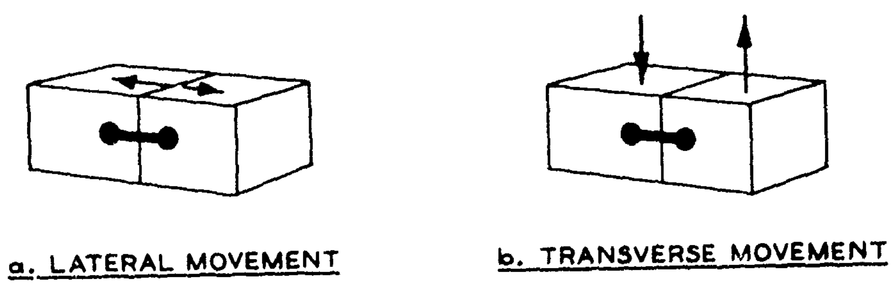

Fig. 2. Joint movements

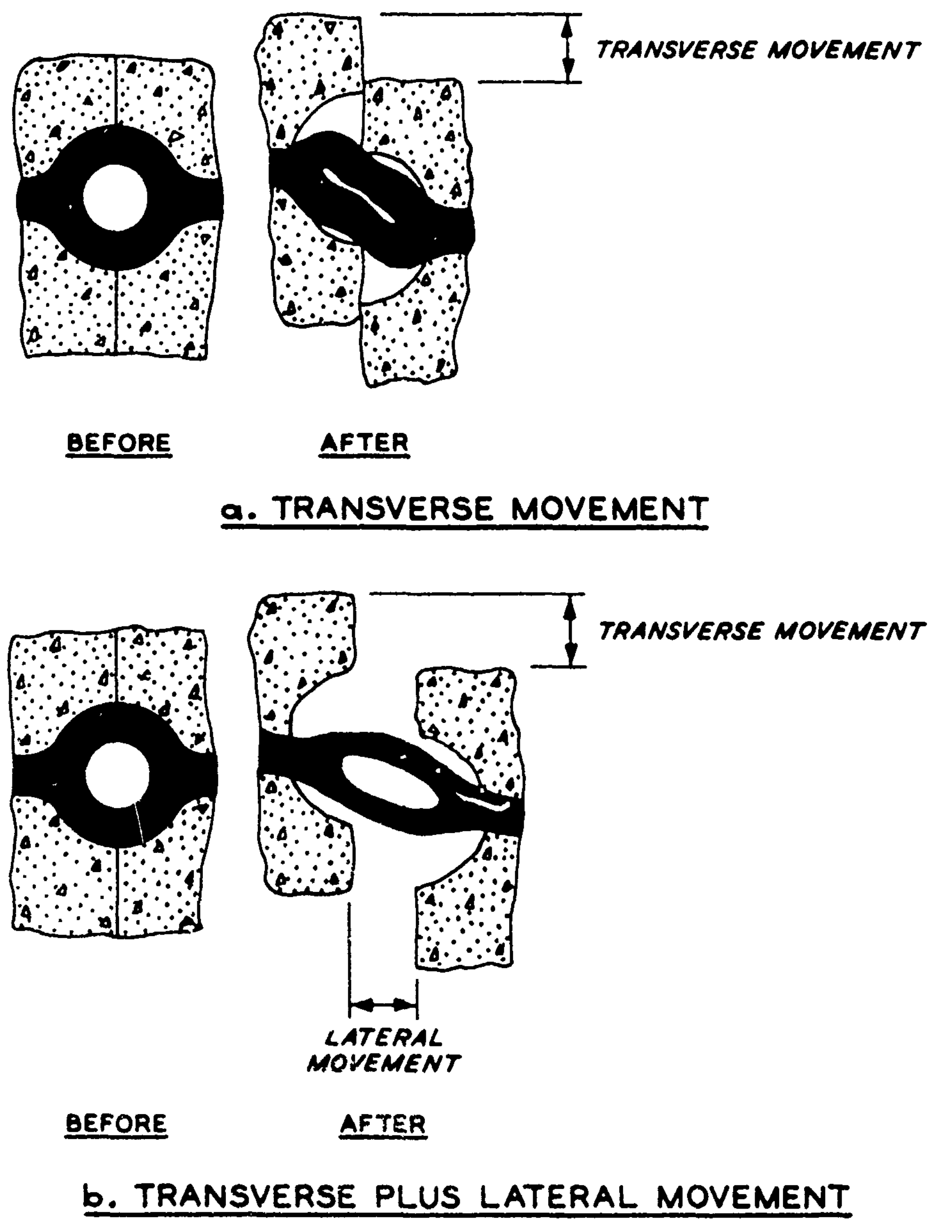

Fig. 3. O-bulb deformations

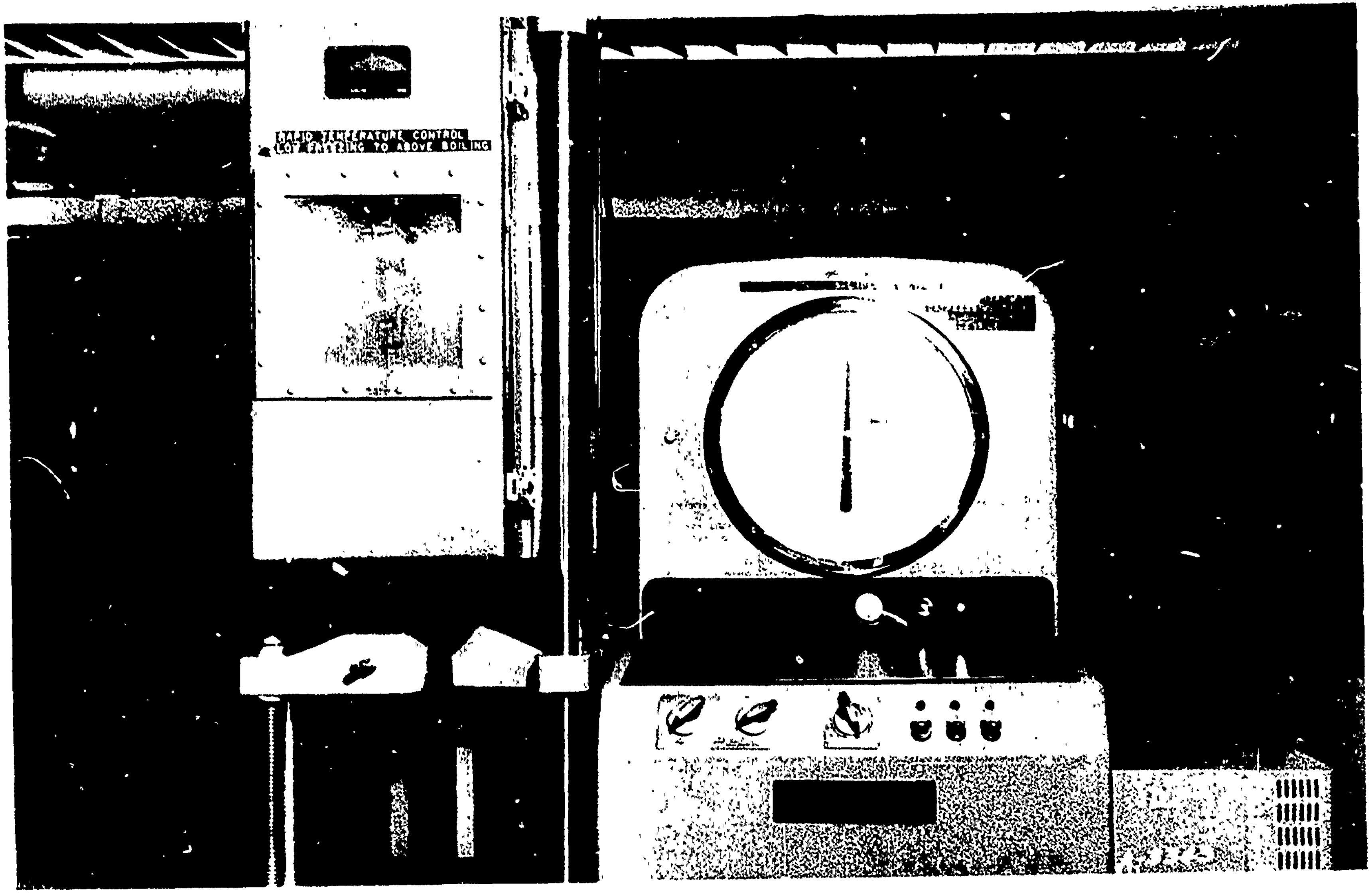

Fig. 4. Environmental cabinet for determining tensile strength and elongation of waterstops at various temperatures

69355

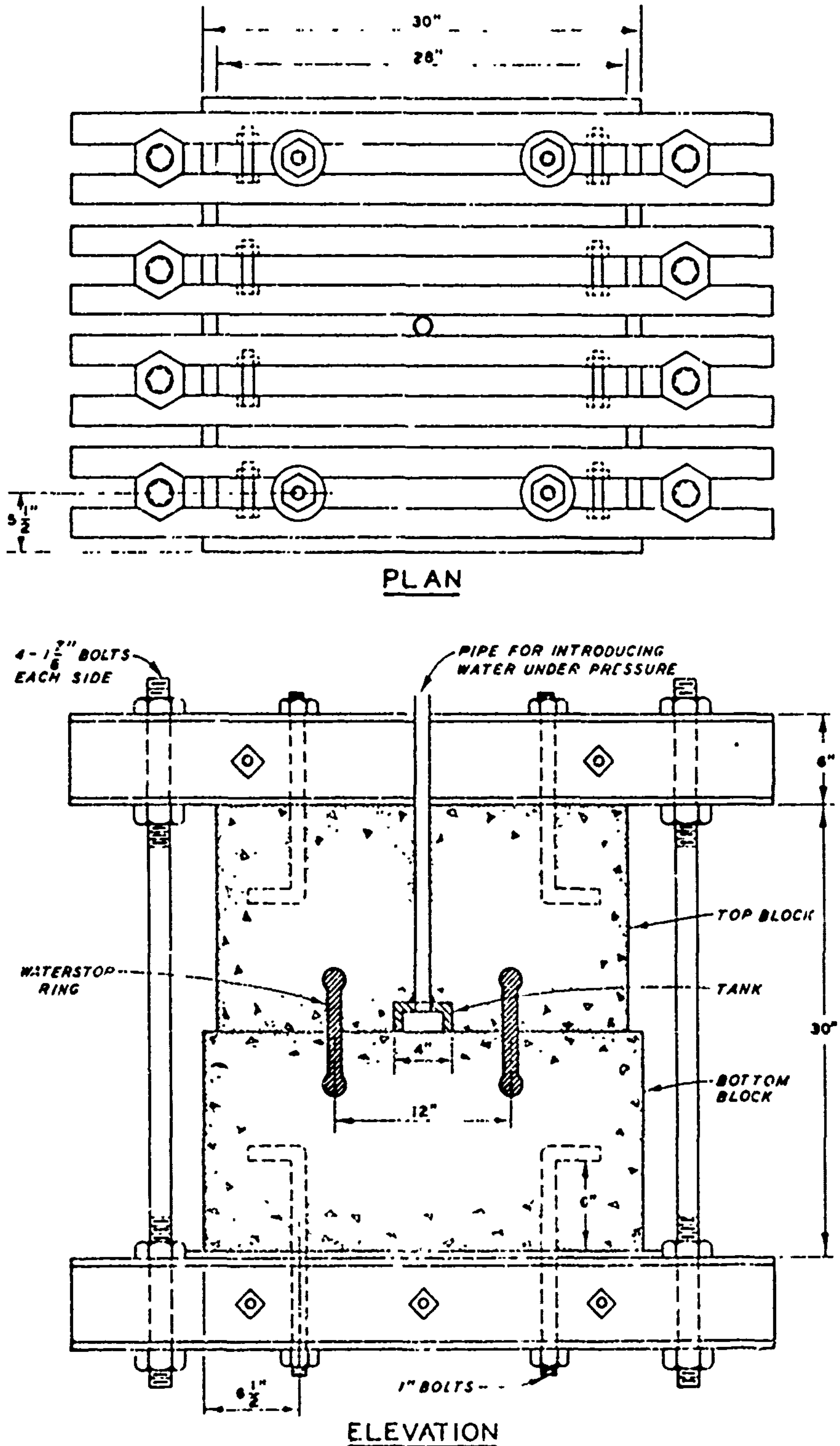

Fig. 5. Water-retentivity test apparatus

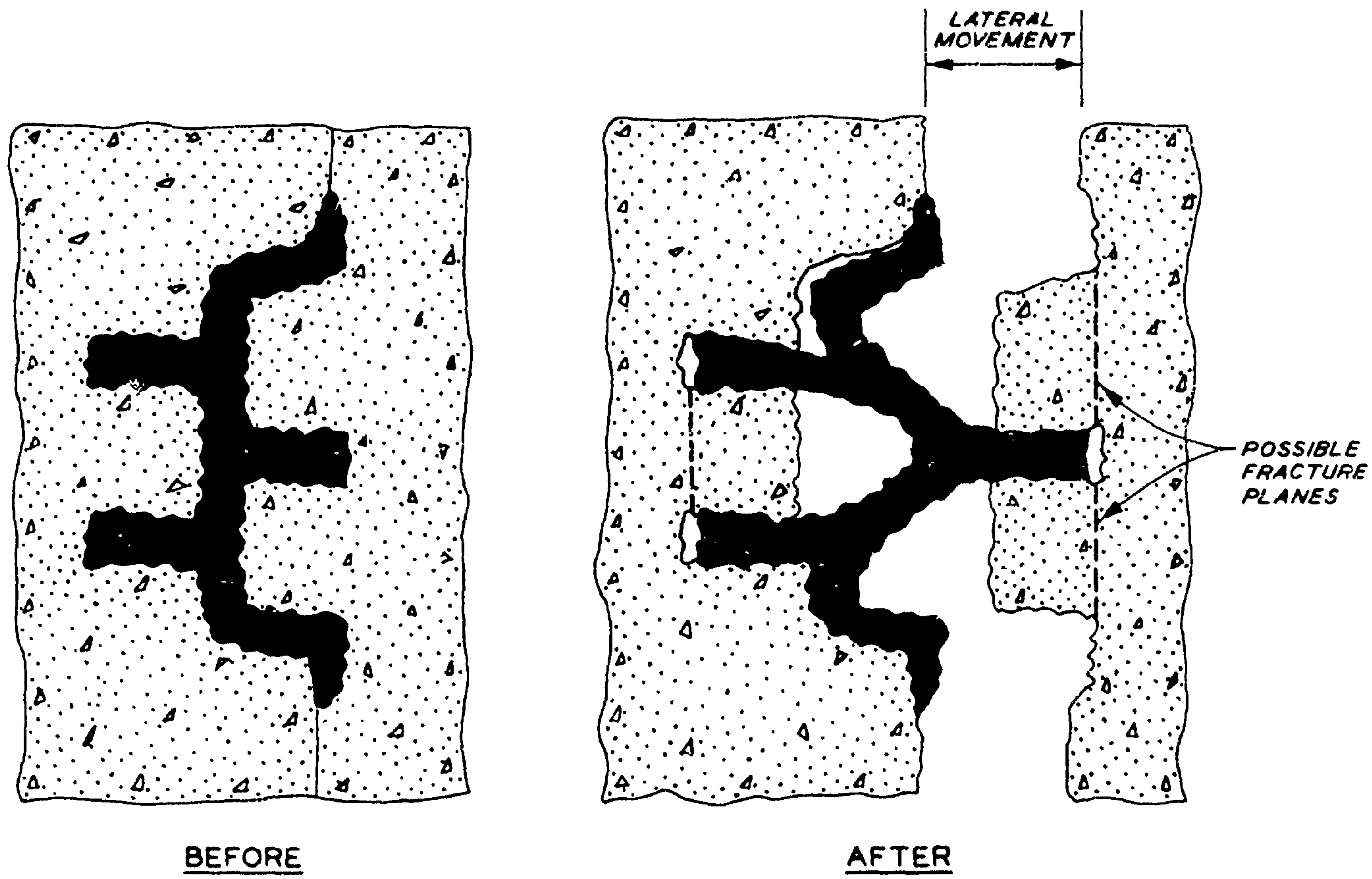

Fig. 6. Labyrinth waterstop failures

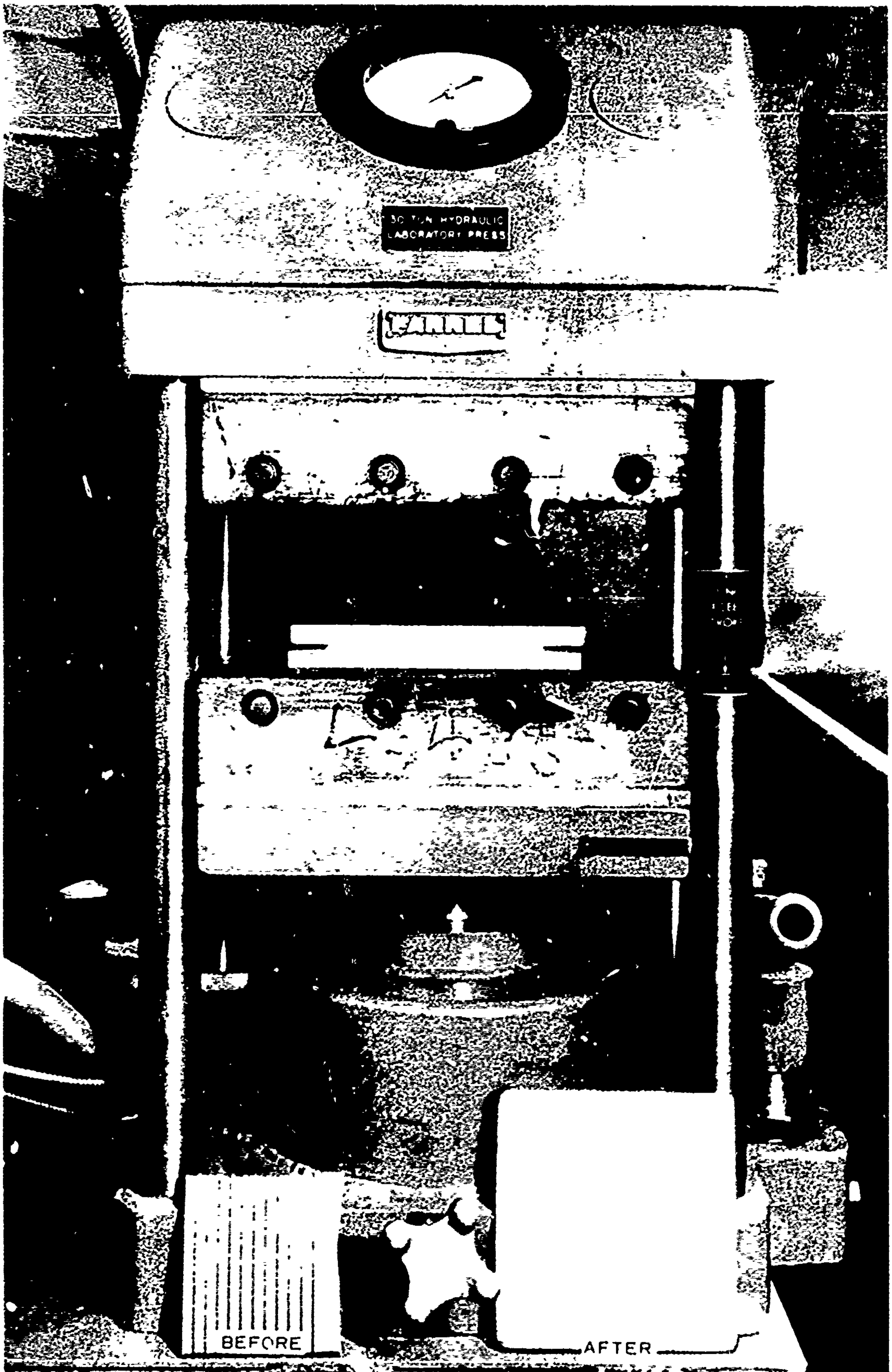

Fig. 7. Hot-press apparatus